Volume 6, Number 1 APPLIED PHYSICS LETTERS 1 January 1965

LASER MODE LOCKING BY AN EXTERNAL DOPPLER CELL

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(Received 17 November 1964)

(He-Ne; 6328A; acoustic cell at 57 Mc/sec; E)

The problem of stabilization of a multimode *c-w* laser can be approached in several ways. Di Domenico[1] has analyzed the rather general case of intracavity modulation of cavity losses, and has predicted that mode locking can occur when the modulation frequency is an integral multiple of the mode spacing. Hargrove, Fork, and Pollack[2] have demonstrated this experimentally, by means of an internal acoustic diffraction cell in a 6328-Å He-Ne laser.

Locking of modes by external means would appear desirable, not only from the standpoint of avoiding modifications to the laser itself, but also because optical losses in the modulator would be of considerably less importance when located outside the laser cavity.

A method of mode locking by external means only has been demonstrated in this laboratory, using the experimental arrangement shown in Fig. 1. An unmodified standard He-Ne laser at 6328 Å is

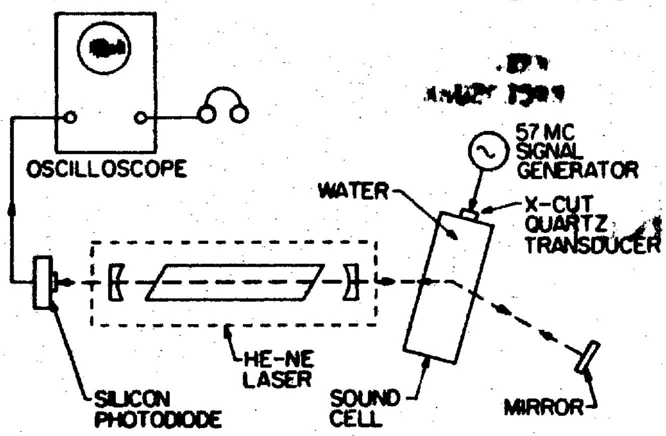

Fig. 1. Schematic diagram of the external locking experiment.

employed, together with a simple ultrasonic Bragg diffraction cell[3] and a mirror, such that doppler-shifted light is fed back into the laser. The resulting laser output is monitored by an appropriate photodetector at the other end of the laser.

When the sound cell is driven at a frequency which is any even submultiple of the longitudinal mode difference frequency ($c/2L$) of the laser, power can reenter the laser cavity after passing through the sound cell an appropriate (even) number of times. This frequency-shifted radiation can then interact within the cavity to produce locking among all the longitudinal oscillating modes.

In the experiment, the sound cell was driven at 57 Mc from a signal generator, chosen to be one-half the laser mode separation of 114 Mc. After the first pass, each laser mode is shifted upward by 57 Mc, and is then reflected by the mirror back through the cell. Each mode is again shifted upward by 57 Mc, and can therefore enter the laser and interact with the next higher frequency mode in the cavity. Downward shifts are equally useful, and are obtained by reversing the direction of sound travel.

Detection was accomplished with an ordinary silicon photodiode, connected directly to the input of a high-gain oscilloscope. In the absence of sound modulation, the second-order beats among three or more modes can easily be observed as audio signals whose frequencies vary in a more or less regular fashion with time, as the modes drift through the gain band of the laser (due to cavity length variations). Typically, the audio beat note is in the kilocycle range, usually descending in pitch. At some frequency between 500 and 1000 cps, the beat disappears for a short time, reappearing in the high kilocycle range. This behavior suggests that the particular laser employed had a weak tendency to lock in the absence of external feedback. Discontinuous changes in the beat frequency in the high kilocycle range were observed; these are believed to be the result of the disappearance of one mode and the emergence of another at the opposite side of the passband. These effects are extremely dependent on the mechanical and thermal environment of the laser; the mode drift can be reversed by slight motions or air currents.

When the sound cell was excited, and the drive frequency carefully adjusted, the observed beats on the oscilloscope disappeared entirely. This constitutes direct evidence of frequency locking among all oscillating modes, since otherwise a low-frequency beat would have been produced. The locking range was quite small, although wide enough for definite observation with an ordinary laboratory signal generator at 57 Mc; a crystal-controlled oscillator would allow locking over an indefinite period.

It was found that when the total external path length was approximately equal to the corrected optical length of the laser cavity, optimum locking was obtained, although no critical length adjustments were necessary. In the experiment, the optical length of the laser cavity was 50 in.; no locking could be obtained at about 25 in., but good results were obtained at 50 in. This condition evidently results in the proper phase of the beat pattern to enhance the existing tendency to lock.

Mode locking by an external doppler cell has the advantage that there is no need to impose any elements inside the laser, which can cause a variety of practical problems. Furthermore, the sound cell is a simple, inexpensive component; when water is employed as the active medium, losses in the visible spectrum are inconsequential.

Another important practical advantage of this method is the possibility of using a cell at a much lower subharmonic of the mode difference frequency, whereas the intracavity methods must use at least one-half of this frequency. Thus it would be possible to construct a sound cell for use in the infrared employing, for example, carbon tetrachloride, which would allow moderate light transmission while at the same time providing relatively good acoustic transmission by virtue of the much

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lower acoustic frequency. Furthermore, as the number of passes through the sound cell is increased, the minimum distance to the mirror decreases in proportion, making possible a more compact arrangement.

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[3]A. Korpel, R. Adler, and B. Alpiner, *Appl. Phys. Letters* **5**, 86 (1964).